

EXPOSURE APPARATUS WITH A PULSED LASER

FIELD OF THE INVENTION AND RELATED ART

10 This invention relates generally to an exposure apparatus and a device manufacturing method using the same. More particularly, the invention is concerned with an exposure apparatus such as a stepper, for example, and a device manufacturing method using the same, suitably applicable to manufacture of various devices such as ICs, LSIs, CCDs, liquid crystal panels or magnetic heads, by, for example, illuminating a circuit pattern of a reticle with pulse light from an excimer laser, for example, and by projecting the illuminated circuit pattern on a wafer.

15 Recently, in an exposure method using an ultra-high pressure Hg lamp, various attempts have been made to enhance the resolution by changing the exposure wavelength to i-line from g-line. Also, many proposals have been made to use pulse light of shorter wavelength, as represented by an excimer laser, to increase the resolution. Use of short wavelength light is effective to enlarge the depth of focus with the reduction in wavelength, to thereby improve the resolution.

25 The emission spectrum of an excimer laser, in a case of KrF excimer laser, for example, is about 300

pm (full width at half maximum), and this is sufficiently small as compared with the full width wavelength of light from conventional ultra-high pressure Hg lamps. Taking the quality into account, the optical material usable in a reduction projection lens of an exposure apparatus which uses light in the deep ultraviolet region might be synthetic quartz or fluorite only. For this reason, taking chromatic aberration into account, even with a spectral band width of 300 pm which is sufficiently small as compared with that of ultra-high pressure Hg lamps, the band width has to be reduced (band-narrowed) further by about two digits. Namely, the full width at half maximum has to be not greater than 3 pm (0.003 nm).

For reduction of the spectral band width, generally, a band narrowing unit having a dispersion element such as an etalon or grating is used to band narrow a laser light to a spectral band width of about 1 pm. While the emission center wavelength of thus band narrowed laser light may differ with a laser medium used, usually a wavelength which is in the vicinity of the emission gain by which a maximum output is obtainable is selected. For example, in a case of KrF excimer laser, it is close to 248.35 nm which is the center of the emission gain.

On the other hand, recent semiconductor

device manufacturing apparatuses are required to provide a high resolution and yet a high throughput. Generally, the resolution depends on the numerical aperture (N.A.) of a projection lens system. Further, for higher throughput, the size of a chip has become larger. This necessitates a projection lens system having a large N.A. and yet a wide field angle.

However, enlargement of N.A. or field angle of a projection lens system directly leads to a difficulty in lens design. Also, it results in narrowed tolerance to production, making the lens manufacture more difficult. For manufacture of a projection lens system, generally, a number of lenses are combined into a projection lens, and trial printing tests are carried out by using that projection lens system. Aberrations of the projection lens system are detected on the basis of the results of trial printing, and correction of the lens system is performed. However, this process needs the skill of an operator and takes much time. Thus, the throughput is low. Also, it is practically difficult to correct all products (projection lens systems) precisely and exactly.

As for a method of quantitatively measuring the performance of a projection lens system having a combination of a number of lenses, there is a method in which an interferometer is used to detect .

aberrations and, on the basis of the detection, the lens system is corrected. Interferometers use a laser as a light source. However, in a case where an excimer laser is used in an exposure apparatus as a

5 light source, there would be no laser source which is suitably usable in an interferometer and which has the same wavelength as that of the excimer laser. Excimer laser of the type used in the exposure apparatus may be used as a light source for the interferometer.

10 However, the coherency of excimer lasers is not high, and they are not suited to be used as a light source of an interferometer. Additionally, because excimer lasers provide pulsed light emission, stabilization of outputs is difficult to attain. Thus, through an

15 interferometer with an excimer laser, it is difficult to obtain good precision in inspection of the performance of a high-quality projection lens system having a large N.A. and/or a large field angle.

Gas lasers such as a He-Ne laser have good

20 coherency and they provide emission of continuous wave. Thus, gas lasers may suitably used as a light source of an interferometer. However, the wavelength differs considerably from that of excimer lasers. Thus, while taking chromatic aberration or film

25 characteristic into account, it is difficult to use gas lasers for inspection of a projection lens system designed for use with the wavelength of an excimer

laser.

In the vicinity of 248.35 nm which is the center wavelength of an ordinary KrF excimer laser, there is a double harmonic wave (a wave having a wavelength a half of its original wavelength) of an argon ion laser, which can be produced by using a secondary harmonic wave producing element. However, such harmonics has a wavelength of about 100 pm which is quite different from that of the KrF excimer laser. Thus, it can not be used as a light source for an interferometer for inspection of a projection lens system designed for use with a band narrowed excimer laser.

SUMMARY OF THE INVENTION

It is accordingly an object of the present invention to provide an improved exposure apparatus.

It is another object of the present invention to provide an improved device manufacturing method.

In accordance with an aspect of the present invention, there is provided an exposure apparatus, comprising: irradiating means for projecting pulse light to a mask; and a projection optical system for projecting a pattern of the mask onto a substrate; wherein the pulse light has an adjusted wavelength such that it substantially coincides with a wavelength of laser light of continuous wave.

In accordance with another aspect of the present invention, there is provided an exposure apparatus, comprising: an irradiation optical system for projecting pulse light of a wavelength 248.25 nm  
5 to a mask; and a projection optical system for projecting a pattern of the mask onto a substrate.

In accordance with a further aspect of the present invention, there is provided a device manufacturing method, comprising the steps of:  
10 providing a light source adapted to supply pulse light of a wavelength 248.25 nm; and projecting the pulse light to a mask so that a pattern of the mask is projected through a projection optical system to a substrate.

15 In accordance with a yet further aspect of the present invention, there is provided a device manufacturing method, comprising the steps of:  
providing a light source adapted to supply pulse light; and projecting the pulse light to a mask so  
20 that a pattern of the mask is projected through a projection optical system to a substrate; wherein the pulse light has an adjusted wavelength such that it substantially coincides with a wavelength of laser light of continuous wave.

25 Projection optical system to be used in the present invention may include a lens assembly, a mirror assembly or a combination of a concave mirror

and a lens assembly.

These and other objects, features and advantages of the present invention will become more apparent upon a consideration of the following description of the preferred embodiments of the present invention taken in conjunction with the accompanying drawings.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic and diagrammatic view of a main portion of an exposure apparatus according to an embodiment of the present invention.

Figure 2 is a graph for explaining the relation between the output and the emission wavelength of a laser light source, in an embodiment of the present invention.

Figure 3 is a schematic and diagrammatic view of a main portion of an embodiment of the present invention.

Figure 4 is a schematic and diagrammatic view of a main portion of an embodiment of the present invention.

Figure 5 is a flow chart of device manufacturing processes, in an embodiment of the present invention.

Figure 6 is a flow chart of a wafer process, in the sequence of Figure 5.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 is a schematic and diagrammatic view of a main portion of an exposure apparatus according to a first embodiment of the present invention.

Denoted in the drawing at 1 is light source means which comprises, for example, a KrF excimer laser for providing pulsed laser light. This excimer laser 1 provides pulse light of a wavelength of about 248 nm in the deep ultraviolet region. Denoted at 2 is a band narrowing unit which includes a band narrowing element such as an etalon or grating, for example, for band narrowing the laser light from the excimer laser 1. Denoted at 3 is a wave meter for detecting the wavelength of pulse light from the excimer laser 1, and denoted at 4 is a beam shaping optical system which serves to expand the beam diameter of the laser light. Denoted at 5 is an illumination optical system for uniformly illuminating a device pattern on the surface (surface to be illuminated) of a reticle R, placed on a reticle stage 10, with the laser light from the beam shaping optical system 4. Through this illumination optical system 10, the reticle surface is illuminated with uniform illuminance distribution.

Denoted at 6 is a projection optical system (projection lens system) for projecting, in a reduced scale, the circuit pattern (device pattern) on the



reticle R surface onto the surface of a wafer W placed  
on a wafer stage 7. Denoted at 9 is a controller  
which is operable to set and control various process  
conditions necessary for the projection exposure of  
5 the wafer W surface. Denoted at 11 is a laser  
controller for controlling the light source means 11  
and the band narrowing unit 2 in accordance with the  
process conditions, set by the controller 9, so that  
the light source 1 provides pulse laser light of a  
10 predetermined wavelength.

In this embodiment, for setting process  
conditions necessary for projection of the circuit  
pattern, on the reticle R surface, onto the wafer W  
surface, for exposure of the latter, initially an  
15 operator inputs, into the controller 9, the necessary  
resolution as required for the projection exposure as  
well as the necessary pulse energy and pulse number as  
calculated from, for example, the sensitivity of a  
resist applied to the wafer W. In response, in  
20 accordance with the applied process conditions, the  
controller 9 operates to determine optimum or  
desirable conditions for the emission of laser light  
from the light source means 1.

The emission conditions may include the  
25 energy of laser light per pulse, emission frequency  
and emission center wavelength, for example. The  
center wavelength of the laser light to be emitted may

be at a level as automatically set by the laser controller 11, or it may be at a level once set by the controller 9 and then transmitted to the laser controller 11. The laser controller 11 continuously  
5 monitors the emitted laser light by use of the wave meter 3 so that the emission wavelength from the excimer laser 1 is maintained at the set emission wavelength. Also, the laser controller 11 controls the band narrowing element (not shown) within the band  
10 narrowing unit 2, so that the wavelength of the pulse laser light is controlled at the set wavelength.

As regards the center wavelength to be set by the controller 9, in this embodiment, in a case where the light source means 1 used in the exposure  
15 apparatus comprises a KrF excimer laser, it is set at a wavelength 248.25 nm which corresponds to the wavelength of double or secondary harmonics of an argon ion laser (wavelength 496.5 nm) of continuous emission type. While an argon ion laser have several  
20 emission lines, a wavelength of double harmonics of 496.5 nm having a relatively high power is close to the emission wavelength of the KrF excimer laser. Thus, the wavelength of exposure light in the exposure apparatus of this embodiment is adjusted or registered  
25 with that wavelength.

The wavelength by which a maximum output is obtainable from the excimer laser 1, having been band

narrowed by the band narrowing unit 2, is about 248.35 nm which is at the center of gain. Thus, setting the emission wavelength of the excimer laser 1 at 248.25 nm results in that the wavelength deviates by about  
5 0.1 nm from the wavelength by which a maximum output is obtainable. However, according to experiments made by the inventors of the subject application, a relation such as illustrated in Figure 2 has been obtained between the laser emission wavelength and the  
10 output.

More specifically, it has been found that, in a band narrowed KrF excimer laser, even if the set emission wavelength is deviated by an order of 0.1 nm from the wavelength by which a maximum output is  
15 attainable, there occurs only a small drop of output of about a few percentages. Generally, in exposure apparatuses, a large decrease in output leads to reduced illuminance on image plane or degraded resolution, and it causes a serious problem. However,  
20 a small decrease of output as having been found by the inventors can be easily compensated by setting the optical system appropriately.

In this embodiment, the design wavelength of the projection optical system 6 and the emission  
25 wavelength of the light source means 1 are registered with the wavelength of a high coherency and continuous emission laser light source, for example, the

Wavelength of double harmonics (continuous wave) of  
laser light from an argon ion laser. Namely, the  
emission wavelength of the excimer laser is adjusted  
and registered with the wavelength of light from an  
argon ion laser. Several methods are applicable to  
registration of wavelength to these lasers (the argon  
ion laser is provided with harmonic wave producing  
means). An example is that both the light from an  
argon ion laser and the light from an excimer laser  
are inputted into a spectroscope and, while comparing  
the difference therebetween, wavelength registration  
may be done. As an alternative, the arrangement shown  
in Figure 3, to be described below, may be used.

In Figure 3, laser light from an argon ion  
laser 29 is wavelength-transformed by means of a  
wavelength transforming device 28, having a secondary  
harmonic wave producing element, by which a secondary  
harmonic wave is produced. This secondary harmonic  
wave is then reflected by mirrors 30a and 30b, and is  
it projected to a wave meter 3. By using this wave  
meter 3, the wavelength of the laser light coming from  
the system including the argon ion laser 29 and the  
wavelength transforming device 28 is measured. With  
the thus detected wavelength, the wavelength of laser  
light from the excimer laser 1 is adjusted and  
registered.

Figure 4 an embodiment of an interferometer

system, wherein the emission wavelength of a KrF  
excimer laser for providing pulse light with center  
wavelength 248.25 nm, to be used in an exposure  
apparatus, is adjusted and registered with the  
5 wavelength of a double harmonics of a continuous  
emission type argon ion laser 29, having high  
coherency, and wherein by using the secondary harmonic  
wave from the argon ion laser the optical performance  
of the projection optical system 6 is measured. In  
10 Figure 4, the laser light of a wavelength 496.5 nm  
from the argon ion laser 29 is wavelength-transformed  
by a wavelength transforming device 28, whereby a  
secondary harmonic wave (wavelength 248.25 nm) of the  
same or substantially the same wavelength of the KrF  
15 excimer laser is produced. It is then directed to a  
collimator lens 6 by which it is shaped into a desired  
beam diameter. Then, the light impinges on a half  
mirror 25.

20 The half mirror 25 reflects a portion of the  
received laser light, and this portion of the light is  
collected by a collimator lens 21 and is directed to  
the projection optical system 6. The projection  
optical system 6 collects the received light, and the  
collected light is then reflected by a spherical  
25 mirror 20 such that the light goes back along its  
oncoming path. The light then passes the half mirror  
25, and by means of an imaging lens 23 the light is

projected on the surface of a CCD camera 24, as measurement light.

On the other hand, the remaining portion of the laser light impinging on the half mirror 25 passes it. The remaining portion of the light, transmitted through the half mirror, is reflected by a reference mirror 22 such that the light goes back along its oncoming path. The light is then reflected by the half mirror 25 and, by means of the imaging lens 23, it is projected on the surface of the CCD camera 24 as reference light.

The image as formed on the camera 24, based on the two light fluxes of measurement light and reference light provides interference fringe (resulting from interference between the two light fluxes) which bears information related to aberration, for example, of the projection optical system 6. The interference fringe is analyzed by an image processing system 27, by which aberrations and the like of the projection optical system 6 are detected. Based on this detection, the optical performance of the projection optical system 6 is measured. Thus, the optical performance of the projection optical system can be well adjusted on the basis of the stabilized laser light as has been described, such that high resolution pattern printing is assured with the thus adjusted projection optical system.

Next, an embodiment of device manufacturing method which uses an exposure apparatus as has been described in the foregoing, will be explained. In this embodiment, the invention is applied to

5 manufacture of semiconductor devices.

Figure 5 is a flow chart of the sequence of manufacturing a semiconductor device such as a semiconductor chip (e.g. IC or LSI), a liquid crystal panel or a CCD, for example. Step 1 is a design process for designing the circuit of a semiconductor device. Step 2 is a process for manufacturing a mask on the basis of the circuit pattern design. Step 3 is a process for manufacturing a wafer by using a material such as silicon.

15 Step 4 is a wafer process which is called a pre-process wherein, by using the so prepared mask and wafer, circuits are practically formed on the wafer through lithography. Step 5 subsequent to this is an assembling step which is called a post-process wherein

20 the wafer processed by step 4 is formed into semiconductor chips. This step includes assembling (dicing and bonding) and packaging (chip sealing). Step 6 is an inspection step wherein operability check, durability check and so on of the semiconductor devices produced by step 5 are carried out. With these processes, semiconductor devices are finished and they are shipped (step 7).

Figure 6 is a flow chart showing details of the wafer process. Step 11 is an oxidation process for oxidizing the surface of a wafer. Step 12 is a CVD process for forming an insulating film on the wafer surface. Step 13 is an electrode forming process for forming electrodes on the wafer by vapor deposition. Step 14 is an ion implanting process for implanting ions to the wafer. Step 15 is a resist process for applying a resist (photosensitive material) to the wafer. Step 16 is an exposure process for printing, by exposure, the circuit pattern of the mask on the wafer through the exposure apparatus described above. Step 17 is a developing process for developing the exposed wafer. Step 18 is an etching process for removing portions other than the developed resist image. Step 19 is a resist separation process for separating the resist material remaining on the wafer after being subjected to the etching process. By repeating these processes, circuit patterns are superposedly formed on the wafer.

In the embodiments described hereinbefore, the projection optical system has a lens assembly. However, it is within the scope of the present invention to use a projection optical system having a mirror assembly or a projection optical system having a concave mirror and a lens assembly.

Further, while in the foregoing embodiments



the wavelength of a secondary harmonic wave of an argon ion laser is applied as the measurement wavelength of an interferometer, if the design wavelength of a projection optical system differs from  
5 that of the embodiments, the measurement wavelength should be changed with respect to the design wavelength. In that occasion, the wavelength of a secondary harmonic wave or tertiary harmonic wave of laser light from an argon laser or from any other gas  
10 laser may be used as the measurement wavelength, and the wavelength of pulse light source to be used for the exposure process may be adjusted and registered to the measurement wavelength.

Further, in the foregoing embodiments the invention has been described with reference to a step-and-repeat type exposure apparatus (stepper).  
However, the invention is applicable also to a step-and-scan type scanning exposure apparatus.

While the invention has been described with  
20 reference to the structures disclosed herein, it is not confined to the details set forth and this application is intended to cover such modifications or changes as may come within the purposes of the improvements or the scope of the following claims.